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9 Valorisation of whey

A tale of two Nordic dairies

Simon Bolwig, Andreas Brekke, Louise Strange and Nhat Strøm-Andersen

9.1 Introduction

Have you eaten Greek yoghurt recently? For every teaspoon of Greek yoghurt you eat, two teaspoons of surplus material are produced. This by-product, known as acid whey, has become a waste disposal issue for dairies around the world following a boom in the demand for Greek yoghurt. This development mirrors, although at a smaller scale, that of sweet whey, which is a by-product of white hard cheese production. Whey is a very strong pollutant, with a biochemical oxygen demand (BOD) 175-fold higher than the typical sewage effluent (Smithers, 2008). With increasingly strict environmental regulation of industrial wastes, disposing of whey as waste has become both difficult and costly as volumes have increased and have become more concentrated in larger production units. Together with a growing societal focus on the circular economy, these environmental pressures have forced the dairy industry to rethink the way it manages its whey side stream (ibid.).

There are valuable substances in whey that are possible to valorise, including functional proteins and peptides, lipids, vitamins, minerals and lactose (Smithers, 2008). In the case of sweet whey, dairies around the world have in recent decades developed technologies, processing capacities, products and new business models for utilising these substances. A strong driver has been the rapid growth in global markets for food ingredients, including whey-based protein powders, which are 'among the winners of several new nutrition trends and food developments' (Vik & Kvam, 2017, p. 336). Thus whey has become an important nutritional and functional ingredient for high-quality foods (NutritionInsight, 2018) and the global whey protein industry has been estimated to grow by 12–14% per year (Kjer, 2013).

This strong market trend is related to rising populations and incomes, especially in emerging economies. But it is also strongly driven by the rise of 'functional nutritionism', which refers to the increased engineering and reengineering of food in coevolution with changing corporate strategies, trends in food, diets and health, and new food and nutrition policies (Scrinis, 2013, 2016; Vik & Kvam, 2017). An indication of this trend is the large and growing market for functional food ingredients, i.e. probiotics, proteins and amino acids, phytochemical and plant extracts, prebiotics, fibres and specialty carbohydrates, omega-3 fatty acids, carotenoids, vitamins, and minerals. In 2018 these were estimated at US$68.6 billion worldwide, rising to US$94.2 billion by 2023 (PR Newswire, 2018). The development of global trade networks and infrastructures associated with globalisation has facilitated the expansion of market opportunities for whey-based products. Upstream in the5value chain, mergers and acquisitions have resulted in fewer and more specialised dairy plants with spatial concentrations of specific side streams, including whey.

Acid whey has not undergone the same development as sweet whey, due to its – so far – much lower volume and somewhat less favourable physical and taste properties (see section 9.2). Yet as this chapter will show, the market and production dynamics just mentioned may also be relevant to acid whey valorisation if issues relating to taste and processing are addressed.

In this broader context, this chapter investigates how the largest dairies in Norway and Denmark, TINE and Arla Foods, have worked to add value to whey with a focus on acid whey. Specifically, we examine key features of the dairy industry in each country, the historical development of these industries, individual firm characteristics and capabilities, and the position of each firm in national and international markets. We ask how these factors – at the level of the firm, the industry and the market – have influenced whey valorisation in the two countries. In this regard, we are especially interested in how the organisation of the firm, e.g. the separation of main product and by-product processing in different legal units, affects organisational capabilities and utilisation of whey.

This analysis draws on theories discussed further in Chapter 3: path dependence and lock-in – particularly economies of scale and scope and learning effects; and directionality through industrial practices – particularly value chain governance. Our comparative approach reveals how these drivers and mechanisms play out in different national contexts and how they influence inter-firm connections crossing these contexts.

This chapter is based on data collected through interviews with experts from a feed producer and from the TINE and Arla Foods dairies, a review of company webpages and a literature review. A total of nine interviews were carried out, of which three were with experts from Arla Foods and Arla Foods Ingredients (AFI) (senior executive R&D advisor AFI, vice president for corporate social responsibility Arla Foods, head of department separation AFI) and six with experts in TINE (research director, head of corporate social responsibility, technical director, researcher and young professional). In this chapter, the term 'whey' is used to refer to both sweet whey and acid whey, unless the type of whey is specified.

The chapter is structured as follows: the next section discusses the properties and utilisation options for acid whey. For each possible use, there is a summary of the current state of innovation, the application's commercial potential, the required technological and investment capacities and the application's place in the waste pyramid. Sections 9.3 and 9.4 present the Norwegian and Danish case studies, respectively. Here we discuss the development and key features of the dairy sectors in both countries, the main characteristics of the dominant dairy company in each country (TINE and Arla Foods) and how these two dairies utilise whey. In section 9.5 we discuss the key drivers of whey valorisation, analysing the dynamics of whey utilisation in the two companies (and countries), concerning the structure of the dairy industry, firm-level characteristics and strategies, and value chain linkages. We then discuss the implications these case studies have for the sustainability of different valorisation pathways. Section 9.6 concludes the chapter.

9.2 Properties and uses of acid whey

Never have we eaten so much Greek yoghurt worldwide, and this trend only seems to be going up. In the USA, approximately 771,000 tons of Greek yoghurt were produced in 2015, accounting for almost 40% of the yoghurt market, compared to a market share of only 1–2% in 2004. However, as the production of Greek yoghurt skyrocketed, so did production of the by-product, acid whey: for every 100 kg milk used in Greek yoghurt production, only one third ends up in the final product, while the other two thirds become acid whey (Arla Foods Ingredients, 2018b). Acid whey is a potential hazard to the aquatic environment due to its high organic matter content in the shape of lactose, resulting in a high Biological Oxygen Demand (BOD > 35,000 ppm) and Chemical Oxygen Demand (COD > 60,000 ppm) (Ramos et al., 2015; Smithers, 2015). The high BOD level means that the presence of acid whey in waters would cause a drop in biological oxygen levels, leading to the elimination of aquatic life. Hence, if other uses cannot be found, acid whey must be treated as waste water in own or municipal plants, involving significant financial costs for the dairy as well as socio-economic costs associated with waste treatment. But acid whey contains many valuable compounds, providing opportunities for companies to gain competitive advantage through value-added utilisation of acid whey, as discussed below (Guimarães, Teixeira & Domingues, 2010).

9.2.1 The properties and composition of acid whey

To understand the properties of acid whey, it is useful to understand the origin of whey. When producing cheese or yoghurts from milk, the milk is separated into a relatively solid part, which becomes the cheese or yoghurt, and a yellow liquid part known as whey (Ramos et al., 2015). Whey can be used directly for animal feed or as a biogas substrate, or processed into a number of products, especially ingredients in food and feed production; see Figure 9.1. Whey has a relatively high protein content and low fat content. There are several types of whey depending on the processing technology used for the casein removal of liquid milk, where the most common categories are

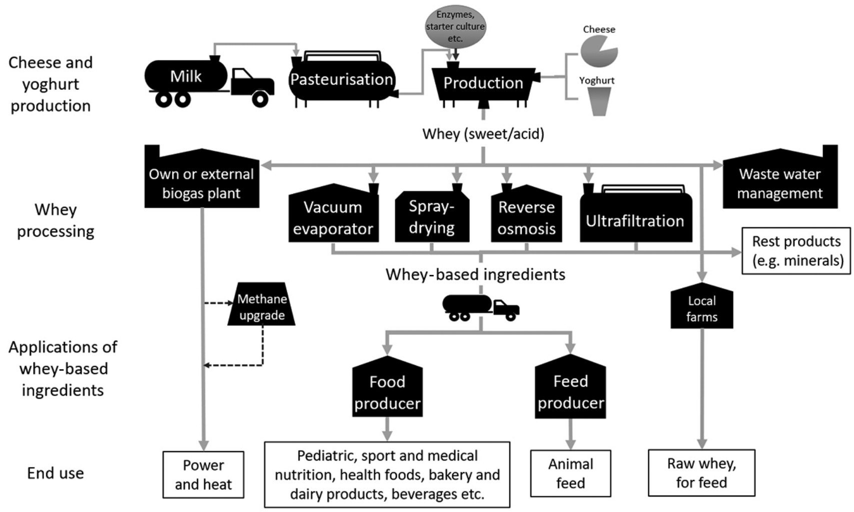

Figure 9.1 Simplified flowchart depicting the processing, application and end uses of sweet and acid whey.

Note
Whey is a by-product from the manufacturing of cheeses and yoghurts especially, as well as of calcium caseinate. Parts of the whey are processed into proteins, whey permeate (milk solids) and other compounds, which are used as ingredients in food and feed production. Whey processing generates its own side streams, including various minerals. Raw whey is used as animal feed, as a substrate in biogas production or treated as waste water.

sweet whey and acid whey (Jelen, 2011; Panesar, Kennedy, Gandhi & Bunko, 2007). Sweet whey is a by-product from white hard cheese production, and can be used to produce a range of functional and nutritional foods (see 9.3.3 and 9.4.3). Different qualities of acid whey are derived from the production of Greek yoghurt, Quark, Icelandic *skyr*, cream cheese and cottage cheese. A variant of acid whey is casein whey, which is derived from the production of calcium caseinate. Calcium caseinate is a protein produced from casein (milk protein) in skim milk and is used in coffee creamers and instant soups and as a dietary supplement by athletes. While some studies such as (Jelen, 2011) often refer to casein whey as 'acid casein whey' or simply 'acid whey', in this chapter we make a distinction between acid casein whey and acid whey derived from the production of Greek yoghurt, *skyr* and cream/cottage cheese, due to the significant differences in properties and potential uses between the two variants of acid whey (interview with AFI).

Both sweet whey and acid whey are composed mainly of water (93%) while the solid components consist of minerals (12–15%), lactose (70–72%) and whey proteins (8–10%) (Jelen, 2011). The largest difference between acid whey and sweet whey is the pH, which lies within 6.0–6.5 for sweet whey (Jelen, 2011) and 3.6–4.5 for acid whey (Gami, Godwin, Czymmek, Ganoe

& Ketterings, 2016), while acid casein whey has a pH of 4.5–5.1 (Jelen, 2011). Overall, compared to sweet whey, acid whey has less protein, is more acidic and has a more distinct (sour) taste. Table 9.1 shows the breakdown of component composition in acid whey derived from yoghurt and cream/cottage cheese production. Below, we focus on the properties and utilisations of acid whey and to some extent acid casein whey, which have been less documented than those of sweet whey (de Wit, 2001; Jelen, 2011).

The challenges of utilising acid whey occur in the processing procedure. The most common way to process whey into a product suitable for industrial use is to dry it through evaporation in multistage vacuum evaporators followed by spray-drying. However, spray-drying acid whey with conventional technology is not feasible due to the high content of lactic acid, which makes the whey powder more likely to absorb moisture, resulting in an increased stickiness of the powder (Chandrapala et al., 2016). Moreover, a low pH makes the proteins less stable and it is more difficult, for instance, to remove water from acid whey than from sweet whey. Because of the low pH and the proximity to the isoelectric point, the protein will readily precipitate, which may make it difficult to recover. Proteins are thus more readily available and easily isolated from sweet whey than from acid whey. Moreover, sweet whey can easily be heat-treated and used in new products (e.g. creamy cheese). If acid whey is heated, it will not become an acidic gel, but unites and acquires a slightly granular consistency.

9.2.2 Utilisation of acid whey

Over the past decades, research and technological innovation have transformed the utilisation of sweet whey from waste (or feed) to a resource for

Table 9.1 pH and nutrient composition of acid whey from the production of Greek yoghurt, cottage cheese and cream cheese

	Unit	*Min*	*Max*	*Average*
pH		3.55	4.48	4.11
Solids	%	2.49	6.53	5.16
Total nitrogen	mg/100 mL	22.4	258.3	85.1
Ammonia-N	mg/100 mL	0.0	16.1	2.8
Organic-N	mg/100 mL	18.9	258.3	82.3
Phosphorous (P_2O_5)	mg/100 mL	120.5	194.0	169.1
Potassium (K_2O)	mg/100 mL	142.5	212.5	192.8
Calcium	mg/100 mL	90.7	136.8	121.6
Magnesium	mg/100 mL	7.1	11.3	9.9
Sodium	mg/100 mL	31.3	44.1	39.3
Sulfur	mg/100 mL	5.0	17.0	7.3
Zinc	mg/100 mL	0.4	0.5	0.4
Chloride	mg/100 mL	79.0	189.0	108.0

Source: Gami, Godwin, Czymmek, Ganoe and Ketterings, 2016.

value-added products (Smithers, 2015). Can such a transformation also occur for acid whey? Below we introduce the most common valorisation pathways for acid whey (including casein whey), drawing on a review of research articles and company websites.

Animal feed

For decades, using acid whey and sweet whey for animal feed has been one of the most common uses of whey due to their nutritional properties. Acid whey is especially suitable for piglets because of the acidity and nutritional composition. In piglet diets acid whey is mainly a source of energy (milk sugar) rather than a protein source.

Many Greek yoghurt and cheese manufacturers still pay their milk suppliers to take the acid whey, which they then mix with silage for animal feed (Smithers, 2015). Although acid whey is a suitable feed, the transport and storage of liquid whey is costly and barely profitable. Some yoghurt makers such as Chobani in the US sell it to local farmers for animal feed supplement (Erickson, 2017b). Chobani has invested in reverse-osmosis filtration technology, which separates the water from the whey using high-pressure systems, resulting in a more compact by-product that is easier and cheaper to transport to farms (Erickson, 2017b).

Biogas

Another common application of acid whey is as a substrate for biogas production, where the biogas is used for electricity production. No estimate of the financial gain for this utilisation could be found. The first environmental gain of using acid whey for biogas production is the avoided risk of spillage of acid whey into the environment. The second gain occurs if the electricity produced replaces electricity made from non-renewable sources and thereby reduces greenhouse gas emissions. Biogas can also be upgraded into pure methane and fed into the natural gas grid, where it exists. In Switzerland, several cheese plants have biogas digesters installed onsite (Jelen, 2011). Alphina Foods (NY) is an example of a company that transports acid whey to a nearby farm, where it is used in biogas production. Some biogas plants, for instance in the UK, run entirely on whey.

Bakery

Some research articles examine the use of the acid whey which stems from the production of the Indian cottage cheese known as paneer, as a bread ingredient (Divya & Rao, 2010; Paul, Kulkarni & Rao, 2016). They report that the inclusion of a moderate amount of acid whey did not have any negative influence on the bread quality, while higher amounts increased the dough proofing time. Research design and results reveal the focus to be on solving the waste problem connected to acid whey rather than finding a truly valuable output for the resource stream. The authors do, however, observe that acid whey contains valuable nutrients suitable for human diets.

Whey beverages

A whey beverage refers to a drink where whey is the main component in liquid form. There are several examples of both soft drinks and alcoholic beverages containing casein whey. Acid whey derived from Greek yoghurt and similar products is not suitable for whey beverages due in part to a too high mineral content. The Swiss brand Rivella is the only one with a reasonable market share and lasting success. Interestingly, Rivella does not advertise the use of acid casein whey in their products, and studies have shown that several international marketing attempts to promote whey beverages have failed (Jelen, 2011). The most typical beverage combination of casein whey is with citrus fruit juices due to the high content of lactic acid. The literature also contains examples of alcoholic beverages such as beer, wine and champagne, which are produced with acid whey. The start-up Alchowhey, created by scientists at the Technical University of Denmark, has developed a DIY patented bacteria solution that converts lactose into ethanol suitable for spirits. The technology is applicable at both large and small scale, which makes it relevant for small dairies which struggle to valorise their surplus whey onsite. Although whey beverages have had very little commercial success due to processing challenges and the unusual flavour of raw whey, a more refined technology and an increasing awareness of the nutritional benefits of whey proteins may encourage the further development of whey beverages (Jelen, 2011).

Nutritional products

Acid whey contains several nutritional components that can be isolated. Research projects have been conducted to isolate valuable compounds, such as lactose, proteins and vitamin B_{12}, while several articles deal with the isolation of substances such as β-lactoglobulin and α-lactalbumin. The latter two are valuable proteins, which are present in significantly smaller concentrations in acid whey in comparison to sweet whey (interview with AFI). Such single components can be used as food additives as well as for medical purposes, where earnings can be even greater. However, most of these processes require complex technologies, which many dairies are reluctant to include in their production lines, and few articles contain references to the commercial recovery of single compounds and substances from acid whey. This can be due to two reasons. First, this process requires new investments and a reorganisation of production, which is unlikely to be supported by dairy managers. Second, the isolation of useful components will result in even less valuable residual material, which will be less suitable for animal feed and require further processing. Casein whey is commonly used in medical nutrition, while acid whey derived from Greek yoghurt is not suitable for this purpose due to its high mineral content. For example, MyProtein® (myprotein.com) used to provide casein whey protein powder used for fitness purposes, but the powder is now out of stock.

Nutrilac®

A recent innovative solution which diminishes the generation of acid whey waste while also maximising product capacity is the protein-based product solution, Nutrilac®, developed by Arla Foods Ingredients (AFI). Nutrilac® does not consist of acid whey but is derived from milk and can be added directly to the acid whey together with water, transforming the acid whey into a low-cost raw material, which can be added to products such as stirred yogurt, beverages, soups, jar cheese, dips, dressings, processed cheeses and cream cheeses (Arla Foods Ingredients, 2018a; Erickson, 2017a). For example, Nutrilac® can be added to acid whey, water and cream, resulting in a high-quality dip. Nutrilac® has won several awards including the 'Beverage Innovation Award' in 2013, the 'IFT Food Expo Innovation Award' in 2014 and the 'IFT Best Dairy Innovation' in 2015. According to AFI, Nutrilac® requires few or no adjustments to existing production lines such as yoghurt or cream cheese while offering a sustainable solution that adds value by expanding companies' product portfolio (Arla Foods Ingredients, 2016).

9.2.3 Innovation, commercialisation and technological requirements

The previous section has outlined the various ways in which acid whey can be transformed into or provide components for value-added products, and at the same time avoid waste disposal or spillage. Yet it also pointed to a generally low level of commercialisation of these conversion technologies, products and components, aside from low-value uses as biogas and animal feed in raw form. In view of this, Table 9.2 provides an overview of the current state of acid whey valorisation for each main use category in terms of: research and innovation, commercial potential, technology and investment requirements, place in the waste pyramid, and use examples.

9.3 The dairy sector in Norway

Historically, the dairy sector has been the backbone of agriculture in Norway and the processing of milk has been dominated by co-operatives owned by milk farmers. Most dairy products found in the cool counter at supermarkets in Norway are labelled TINE while a smaller portion comes from the brand Q-Meieriene. Foreign dairies such as Danone and Arla supply an even smaller portion. The Norwegian dairy sector has experienced a strong structural development, going from many small, almost independent dairies to a few, large and highly efficient ones. A similar transformation has taken place

Table 9.2 Overview of acid whey valorisation

Use	*Research and innovation*	*Level of commercial potential*	*Technology and investment requirements*	*Place in the waste pyramid*	*Use examples*
Animal feed	Acid whey is commonly used for animal feed. Important nutrients are maintained during processing and drying using modern technology. This makes the product highly palatable and digestible for calves, goat kids and lambs. Acid whey is especially suitable for piglets due to its acidity and nutrients. It is mainly a source of energy (milk sugar) rather than protein.	High level of commercial potential due to the wide range of different physical parameters available in whey products.	Feed producers need high-quality processing equipment, storage space, silos, transportation and warehousing.	Reuse/upcycling of nutrients in the whey.	The US yoghurt producer Chobani has adopted advanced filtering systems in its Idaho and NY plants and provides whey as supplemental feed to local farmers.

Biogas	Anaerobic digestion treatments are well developed for biogas production.	Biogas can be used locally for electricity or process heat, or can be upgraded to and sold as bio-methane. Installing the digester at the location of whey production saves transport costs but requires more volume.	Requires no changes in production processes. Investment in a biogas plant can be costly for small dairies; state support has in some cases helped overcome this barrier. Whey can also be sold to an external biogas plant.	Recovery (energy) and recycling (digestate applied on fields).	The world's largest biogas plant, located in the UK, runs on whey. In the US, Alphina Foods (NY) uses a bio digester on a nearby farm, resulting in 100% processed acid whey.
Bakery products	Using raw acid whey material in bakery products has not reached a solution. Bakery products can be upgraded by using acid whey together with Nutrilac® (see below).	There is little nutritional advantage to be gained from using acid whey as a substitute for water in baking. Moreover, the demand for bakery products containing acid whey is still low.	Does not require major changes to production systems.	Reuse.	No examples could be found.
Whey beverages	The food industry and scientists are increasingly assessing the use of acid whey in beverages due to its favourable nutritional composition. Innovations within alcoholic beverages are also gaining ground.	Acid whey beverages have not yet been successfully adopted by the market, so commercial potential is still low. Solutions like Nutrilac® may increase the market potential, as may the production of alcohol from whey.	Requires handling of acid whey and product development in the production of whey beverages.	Recycling.	Rivella is the only successful acid whey beverage on the market. Alcowhey is using a patent bacteria solution to make ethanol from whey. Arla Foods has also created acid whey beverage possibilities.

continued

Table 9.2 Continued

Use	*Research and innovation*	*Level of commercial potential*	*Technology and investment requirements*	*Place in the waste pyramid*	*Use examples*
Nutrition	The food industry is now focusing on the health aspects of acid whey with regard to nutritional opportunities in food products. Extracting functional components of sweet whey has become a major industrial activity, but for acid whey it is still mainly in a research state.	Using the many nutritional properties of acid whey has high market potential, when considering the many current uses in food ingredients of similar properties of sweet whey.	Requires investments in complex technology for separation and for the production of specific components.	Reuse/upcycling of nutrients in the whey.	MyProtein® fabricates acid whey protein powder for fitness purposes.
Nutrilac®	Nutrilac® technology has created new possibilities for the use of acid whey, according to AFI.	Nutrilac® can increase the commercial potential of the uses of acid whey in a variety of by-product developments.	No technological investment is needed. Companies will have to purchase Nutrilac® from AFI.	Enables reuse and recycling.	Arla Foods is producing value-added products using Nutrilac®, and Nutrilac® is sold to other food producers.

upstream in the value chain. The number of milk farms fell drastically from 148,000 in 1959 to 16,000 in 2009, further declining to 8,800 in 2015 (Almås & Brobakk, 2012; Statistics Norway, 2016).

TINE is obliged to collect all milk from farmers in Norway, irrespective of the distance of the farm to the nearest dairy. This requirement is connected to a general national policy of decentralised development in a vast, sparsely populated country.

In Norway the agricultural sector is highly protected and TINE does not have the 'political mandate' to source from other countries (which for instance led to what is known as the 'butter crisis' in 2011 (Aftenposten, 2011)). In addition to high transportation costs, Norway faces tariffs when exporting food to the EU. Trade between Norway and the EU is regulated through the 1992 Agreement on the European Economic Area (EEA Agreement) and tariffs and quotas for agricultural products are negotiated under this Agreement, most recently in April 2017 (European Commission, 2017). The agricultural trade balance favours the EU (ibid.) and EU exports to Norway are increasing, with the product category 'fresh milk and cream, buttermilk and yoghurt' rising from €14 to 19 million between 2013 and 2017. Norwegian exports to the EU of products in the same category remained stable at €3 million from 2013 to 2017 (European Commission, 2018). According to Vik and Kvam (2017), EU import tariffs mean that the EU is not an important market for Norwegian whey protein concentrate.

9.3.1 TINE in Norway

TINE is by far the largest dairy cooperative operating in Norway. It traces its history back to 1856 when Rausjødalen Meieri – the first dairy cooperative in Norway and Northern Europe – was founded with 40 members. During the second half of the 19th century, the organisation expanded as still more dairies were established, and the Norwegian Dairy Association was founded in 1881. The year 1900 saw the highest number of dairies in operation with 780 sites in total. A few cheese brands were interesting to the international market, and in the 1920s, an organisation was established to handle the export of dairy products from Norway. The name TINE was introduced in 1992 and the company structure has changed a few times since (TINE, 2018a).

Today, the TINE cooperative has 10,500 members (owners) and 8,500 cooperative farms (TINE, 2018b). Farmers are guaranteed milk sales to dairies through the cooperative and dairies are guaranteed a supply. Milk production is the most regulated activity in the Norwegian agriculture sector. A central agreement on the milk price ensures an equal price to all farmers, irrespective of the use of the milk or the farm's geographical location.

From the year 1900 up to the 1980s there was a gradual decrease in the number of dairies from 700 to about 200. Instead of having a dairy at or near each farm, regional dairies were established. They were located to efficiently collect milk from the surrounding farms and supplied almost the entire product portfolio to the regional market. The decrease in the number of dairies between 1900 and 1990 was accompanied by an increase in the size of regional dairies. Since the introduction of the TINE brand in 1992, restructuring has been associated not only with larger dairies but also with a higher degree of specialisation. Today, TINE has 31 dairies (TINE, 2018c) and no ambition to produce the entire product portfolio at each dairy. Instead, the company operates a complicated logistical system where intermediate products are transported between dairies and end products are transported from dairies to regional and central warehouses.

Yet TINE is more than a processor of milk. As mentioned, transport and storage logistics are important parts of the company. There are also strong connections upstream in the value chain back to the farms. This is emphasised in TINE's contribution to R&D within animal health and milk production especially, which focuses on a strong relationship with the Norwegian University of Life Sciences and with other Norwegian universities and research centres.

9.3.2 Utilisation of acid whey in Norway

The 'discovery' of large streams of by-products such as acid whey has been a consequence of the restructuring and specialisation of Norwegian dairies since the early 1990s. When each dairy still produced a great variety of products, the amount of each type of by-product was small and easy to handle through wastewater treatment. The moment cottage cheese and Greek yoghurt were produced at a single facility, at the same time as the demand for these products grew tremendously, the volume and spatial concentration of acid whey also increased and became difficult to handle.

TINE is one of the main suppliers of Greek yoghurt and cottage cheese in Norway and is therefore also a major producer of acid whey. Because of the rising volumes of acid whey, adding value to this by-product has become a new focus area for TINE. TINE produces several thousand tons of acid whey each year, which come mainly from one of its 31 dairies, located in southern Norway. It has been a challenge for TINE to handle the increasing volumes of acid whey because it cannot be treated or used in the same way as sweet whey. Today, acid whey is mainly used in low-value applications, namely directly as animal feed (to pigs) and biogas production. Acid whey can be used in the production of piglet feed, and can obtain a rather high price per kg dry matter, but no Norwegian dairies sell acid whey to feed producers (interview with feed producer). This is probably because it is not deemed profitable given the investment costs and control of processing needed to make a raw material suitable for the feed industry.

TINE delivers free acid whey directly to farmers, who pay half of the transport costs. Another dairy company in Norway also delivers acid whey to farms, with a more stable chemical composition and more dry matter, which the farmers pay for. A reason for this difference is that TINE makes both cottage cheese and Greek yoghurt, which tends to give more variation in acid whey properties, as it is derived from two different processes, while the other manufacturer only produces Greek yoghurt (interview with TINE and feed producer).

9.3.3 Utilisation of sweet whey in Norway

Although TINE treats acid whey almost like it has no value, the same is not true for sweet whey. Sweet whey is made into whey protein concentrate (80% total whey protein content) and its coproduct whey permeate (milk solid) at two new facilities located in Jæren and Verdal. Whey permeate contains 85% lactose and only 3% protein, and can be used as an ingredient in bakery products, confectionary, dairy products, sauces, drinks and similar food products. Whey raw materials are supplied by TINE from its production of yellow cheese. The facilities went into operation in 2013 and were built (Jæren) or upgraded (Verdal) with technical assistance from AFI, with whom TINE has had a partnership based around whey since 2008 (Arla Foods Ingredients, 2018a). This partnership also stipulates that AFI is the sole distributor in export markets of all the whey protein concentrate and whey permeate produced by TINE. TINE exports around 2,800 tons of whey protein concentrate and 21,000 tons of whey permeate each year through AFI (Vik & Kvam, 2017). Prior to 2008, TINE relied on different traders for whey powder exports (ibid.). The partnership gives TINE access to AFI's global sales channels and in turn helps AFI to increase its global market share. AFI has furthermore invested in infrastructure, logistics and quality systems to facilitate the export of Norwegian whey-based substances (Vik & Kvam, 2017).

9.4 The dairy sector in Denmark

Danish dairies have received worldwide recognition for their processing skills and product quality, and their products are present across the world. The Danish dairy sector comprises 28 companies and 54 production plants, processing around 4.9 billion kg milk (Danish Dairy Board, 2018a). Cooperatives of milk producers are the dominant ownership model and 97% of the milk produced in Denmark is supplied to cooperative dairy companies. Over the last century the number of dairy companies fell dramatically to the present level (see below).

Arla Foods is by far the biggest dairy company and cooperative in Denmark and Sweden. In 2017, Arla Foods processed 87% of the Danish milk pool (Danish Agriculture & Food Council, 2018) and 66% of the Swedish milk pool. In Denmark, the remaining dairies are both cooperatively and privately owned companies. They typically specialise in specific product areas within cheese, butter and liquid milk production (Danish Agriculture & Food Council, 2018). A large part of their production is exported by specialised exporters.

As in Norway, the Danish dairy sector has gone through tremendous structural changes over the last decade, with production now taking place on a small number of large farms. According to Statista (2018), the number of Danish dairy farms decreased by almost 50% (from 6,253 to 3,293 farms) in the period 2005–2016. In 2010, approx. 4,100 dairy farmers each had an average of 127 cows and a milk quota of 1,142 tonnes (Danish Agriculture & Food Council, 2018), which made the Danish dairy sector among the largest and most modern in Europe.

Danish dairies are strongly export oriented and two-thirds of the total Danish milk pool go into export products, placing Denmark among the world's top five exporting nations (Danish Dairy Board, 2018b). The historical focus of Danish agriculture on export markets (butter and bacon to the UK) has enabled the specialisation and growth of the dairy industry, generating increasing volumes of side streams. The value of all Danish dairy exports equals €1.8 billion annually (Danish Agriculture & Food Council, 2018), representing more than 20% of all Danish agricultural exports (Danish Agriculture & Food Council, 2018). The largest export market for Danish dairy products is the EU. Exported dairy products are mostly cheese, preserved milk products and butter. The domestic market is mainly covered by domestic dairy production (Danish Agriculture & Food Council, 2018). The market share of imported milk is modest.

9.4.1 Arla Foods

Arla Foods is part of the Arla Group, which has its headquarters in Denmark. It is Europe's largest dairy group and the fourth largest in the world in terms of milk intake (Hansen, 2018). It is owned by 11,262 milk producers across seven European countries, most of them in Sweden (2,780), Denmark (2,675), Germany (2,327) and the UK (2,395) (Arla, 2017). In total, Arla processes 13,937 million kg of milk, of which 35% comes from Denmark, 23% from the UK and 13% from Sweden and Germany respectively (ibid.).

Arla's journey began back in 1882 when the first Danish dairy cooperative was established, while farmers in Sweden set up their first cooperative in 1881, calling it Arla Mejeriforening (Arla Foods Ingredients, 2018a). The dairy cooperative movement quickly took off and in 1890, there were 900 cooperative dairies in Denmark, and 10 years later the number had reached 1,000. The cooperatives grew in size and scope throughout the 20th century and in 1970, four large cooperatives and three individual dairy farmers formed Mejeriselskabet Danmark (MD). The creation of MD required the construction of a more professional organisation to include modern strategic and functional management. MD was continuously developed through mergers and growth in the following two decades, resulting in the establishment of the more internationally oriented MD Foods in 1988. In 2000, MD Foods and Swedish Arla merged and changed their organisation's name to Arla Foods. At the time, the two companies processed 90% of the Danish and 66% of the Swedish milk pool respectively.

Arla Foods Ingredients: AFI

In Denmark, the discovery of the potentials of whey protein began in 1974 when the first pilot production of whey proteins was established in the cellar of a milk powder plant owned by the dairy cooperative in Holstebro (today, Arla Hoco). Whey, which was hitherto regarded as waste, proved to be, as Arla declares, 'full of wonders', and in 1980 Danmark Protein opened the world's largest factory for the production of whey protein concentrate and lactose (milk sugar). In 1988, Danmark Protein established a subsidiary in Japan, while MD Foods established MD Foods Ingredients in Germany in 1990 (Arla Foods Ingredients, 2018a). In 1994, MD Foods then acquired Danmark Protein, which was merged with MD Foods Ingredients. A similar development was seen in Sweden. With the merger of the mother companies in 2000, MD Foods Ingredients became AFI.

Today AFI is an independent subsidiary of Arla Foods and is responsible for all Arla Food's whey protein products destined for the global B2B market for functional and nutritional ingredients. The head office is located next to Arla Foods in Viby, Denmark, and it has subsidiaries across the globe (see below). The company has 1,370 employees. AFI has experienced high growth rates over the last few years. In 2017, the revenue of AFI was €655 million, and €766 million including its joint ventures (Arla, 2017). This represents a revenue increase of 19.6% compared to 2016. AFI has also seen a relative growth in both the scope and quality of its product portfolio; the share of the volume of 'value' products compared to 'standard' products grew from 68% to 74% between 2012 and 2017 (ibid.).

Maintaining or increasing market share in a fast-growing global market for whey-based products requires large investments. AFI invested €220 million in value-adding activities between 2012 and 2017 (Arla, 2017). A large share has been directed towards expanding and refining its domestic production capacity. This includes a €57 million investment in 2012 that nearly doubled AFI's whey processing capacity in Denmark, and a new lactose factory in 2013 worth €120 million. In 2016, a new production facility for whey protein hydrolysate, used in infant, sports and clinical nutrition, went into operation, tripling AFI's existing capacity in this production category.

Today AFI processes 6–7 million tons of sweet whey every year on its Danish facility in Nr. Vium. This includes 400,000 tons of casein whey, derived from the production of calcium caseinate at Arla Hoco (interview with AFI). To utilise the full capacity of the plant, AFI also imports sweet whey from Sweden, the UK and Germany, and it buys sweet whey from other Danish dairy companies. The products produced from sweet whey are described in section 9.4.3.

AFI invests significant resources in research and development (R&D). Its R&D division employs 70 scientists and technicians, accounting for 10% of all AFI employees, and collaborates closely with universities. The R&D covers 'tailoring of molecular functionality, advanced separation technologies to isolate specific components, heat treatment and pasteurization technology to improve functionality and shelf-life. R&D further develop powder technologies to form safe and functional powders for dry blend and optimal rehydration' (Arla Foods Ingredients, 2018c).

In 2009 AFI established a large high-tech ingredients application centre in Aarhus, Denmark to substitute the more modest application facilities at the R&D pilot plant in Nr. Vium. Another, smaller centre was established in Buenos Aires in 2002. The innovation centres are used for both whey protein research as well as for product trials. A key purpose is to assist AFI's customers in utilising the whey-based ingredients sold by AFI in their product development.

The Danish dairy ingredients subsector has shown an even stronger export market orientation than conventional dairy products, responding to the rapid growth in demand worldwide. Since 1990, MD Foods Ingredients/AFI has established overseas subsidiaries in Europe, the US, Asia (Japan, China, Singapore and South Korea) and South America (Argentina, Brazil and Mexico). The internationalisation strategy includes foreign direct investments in whey processing plants in Argentina (from 2002 to 2018) and Germany (1993, 2002 and 2011) facilitated by joint ventures and acquisitions (Arla Foods Ingredients, 2018a). A key purpose of these investments is to increase access to whey raw material, which is critical to maintaining AFI's market share (Kjer, 2013). In the other countries mentioned, direct investments have mainly been in the form of sales offices. In 2008, a partnership was created with the TINE dairy in Norway (see 9.3).

9.4.2 Utilisation of acid whey in Denmark

Arla Foods generates limited amounts of acid whey from the production of *skyr*. This whey contains mainly lactose and calcium and very little protein. It is therefore not further processed but until today only used as a biogas substrate, as markets need to be found for potentially innovative solutions (interview with AFI). As mentioned, AFI has developed a whey protein product called Nutrilac® that can upgrade acid whey functionality so it can be used in the production of a range of products (see 9.2.2). AFI sells Nutrilac® to customers including producers of dairy products.

9.4.3 Utilisation of sweet whey in Denmark

Up to the 1980s, whey from cheese production in Denmark was mainly used for animal feed, but today whey-based products have become the main commodities, which may even create a higher value than the cheese production itself. Arla Foods Ingredients is the only company in Denmark that processes sweet whey on an industrial scale. It also owns processing facilities in Germany and Argentina and it markets whey products produced in Norway. AFI products are sold in more than 90 countries (Arla, 2017). They include a range of functional and nutritional ingredients (proteins) to support industries within paediatric nutrition, sport nutrition, health foods, medical nutrition, bakery products, dairy and affordable food (Arla, 2017). The proteins produced include 15–20 'pure proteins' such as whey protein concentrate, whey protein isolate, Lacprodan and Capolac Nutrilac, among others. From these proteins, other and new 'mixed' proteins are constantly being developed so that the total number of proteins produced and sold at any given time ranges between 80 and 150 (Hansen, 2018). Likewise, AFI produces whey permeate, a coproduct of whey protein concentrate, on its plants in Denmark and Argentina and sells the whey permeate produced by TINE (Arla Foods Ingredients, 2018d) (see 9.3.3). A substantial part of the permeate production is further valorised into different qualities of lactose mainly used for infant formula production (interview with AFI).

9.5 Discussion

9.5.1 Drivers of whey valorisation

In just a few decades, the production of whey-based food ingredients has become an important part of Arla Foods's overall strategy. The development of these side streams has been significant for the company's strong position within value-added activities today (Lange & Lindedam, 2016) and the aim of AFI is to become 'the global supplier of value added whey' (Arla, 2017, p. 34).

Arla Foods has employed several strategies to strengthen its position in a very dynamic global market for whey-based products. A key factor has been the establishment of the subsidiary AFI dedicated to whey processing, as well as joint ventures between AFI and foreign ingredients companies. This has provided the needed organisational framework for their large investments in raw material sourcing, production capacity, R&D and marketing of value-added whey over the last two decades. In general, subsidiaries bring internationalisation opportunities, and they also enable the creation of more direct customer contact as well as consumer control, resulting in increased governance features for the subsidiary in the respective location (Biisgård, 2006). AFI thereby enables the creation of a more tailored product portfolio within their main markets (Danish Dairy Board, 2006). Moreover, AFI has created three business units for specific products, thereby enhancing its capacity for product differentiation and specialisation: nutrition, functional milk protein, and permeate and lactose (Andersen, 2014). In support of their business units, AFI has a large R&D division and runs two customer-focused application centres. All this has contributed to Arla Foods becoming a 'lead firm' (Gibbon, Bair & Ponte, 2008) in the global value chain for whey proteins, sourcing whey not only from its own member producers but also from other dairies in Denmark and Norway (see below).

Nutrilac® may be an efficient way of dealing with acid whey today, at least for high-value end products. Yet it is presently only available in limited volumes and the challenge for AFI is therefore to identify markets with a moderate demand for the innovative solutions (interview with AFI). Thus it remains to be seen whether Nutrilac® will become a dominant technology in acid whey valorisation and if other processing solutions are developed and commercialised alongside this one.

As noted in Chapter 3, lock-in mechanisms not only create barriers to innovation in the bioeconomy, but can under certain conditions promote and reinforce innovation and sustainable business development. In this regard, as a result of a series of mergers and acquisitions, foreign direct investments and technological specialisation over the past decades, Arla Foods has realised positive lock-in mechanisms in whey-based activities. These are economies of scale (in whey sourcing, processing and marketing), economies of scope (regarding production and marketing of different whey products) and long-term learning effects (regarding whey sourcing, processing technology and markets). A key factor has been the establishment of the subsidiary AFI with an R&D department dedicated to whey product development. Important economic and political contexts have been the fast-growing global ingredients market, good access to regional (Northern Europe) whey resources and a basis in an export-oriented agricultural sector (see Table 9.3). All this represents a strong 'directionality through industrial practices' (Chapter 3) in whey valorisation, which was originally motivated by a growing waste problem.

Currently, TINE has had no explicit strategy for adding value to its side streams and is still establishing a strategy for acid whey in cooperation with a Norwegian research institute (interview with TINE). Most of TINE's R&D focuses on end products, health, packaging and animal health. The main focus within TINE has been on how to manufacture end products most efficiently, while the handling of by-products has received less attention. The department called 'Ingredients' does not have a special focus on surplus resources, but rather on the needs of the food industry. This means that they do not search for alternative uses of surplus resources from the dairies, but respond to demand from a specific market. There is an emphasis on keeping production and products stable, and on not interacting with existing production infrastructure in the utilisation of side streams.

For side streams TINE has emphasised reducing the costs of management rather than increasing the value added. For acid whey, this choice is related to the rather small volume of acid whey generated (even with the increase in Greek yoghurt and cottage cheese production), which makes valorisation less attractive in a cost-benefit analysis. It is also related to TINE's current lack of an international market channel for acid whey-based products (interview with TINE). In the case of sweet whey, which is much more abundant, TINE's partnership with AFI has enabled the co-production of two bulk commodities – whey protein concentrate and whey permeate. But TINE depends on AFI for the marketing of these products and does not engage in more refined processing or product development, and it also depends on AFI for building or upgrading its processing facilities. From a value chain governance perspective (Gereffi, Humphrey & Sturgeon, 2005), this places TINE in an

Table 9.3 Summary of dairy industry dynamics and whey valorisation pathways

Firm and country	*Characteristics and dynamics*	*Economic context*	*Political context*	*Whey valorisation*
Dairy industry in industrial countries	Fewer and more specialised dairy plants, resulting in spatial concentration of specific side streams.	Fast-growing global market for functional and nutritional food ingredients.	Stricter environmental regulations: need to process whey or pay for waste disposal.	Ranges from simple energy recovery to advanced processing into high-value food ingredients.
TINE (Norway)	Large cooperative dairy in national context. No strong focus on by-products. TINE Ingredients is a department, not a separate company. Own, large R&D centre. Relatively small plants.	Strong value chain relations with milk suppliers, regulated by law. Geographically dispersed farms.	Strong regulation of dairy industry; protection from foreign products. Not a member of the EU.	Producer of few sweet whey-based ingredients. No processing of acid whey.
Arla Foods (headquarters in Denmark)	Large cooperative dairy in national and global context. Has grown through mergers and acquisitions, joint ventures and investments in whey processing capacity. High R&D and marketing capabilities related to food ingredients. Has set up a separate ingredients company, which handles and sells by-products. Relatively large plants.	Export-oriented agricultural sector. Liberalised national market. Large farms located close to each other and to the dairies.	Easy access to EU markets. Export-friendly policies.	Producer of multiple sweet whey-based ingredients. No processing of acid whey. Developed Nutrilac®, which eases the use of acid whey as an ingredient in high-value products.

asymmetric and 'captive' supplier relationship with AFI (Vik & Kvam, 2017), where the latter's control of research-based knowledge of processes and products as well as customer relations makes it costly and risky for TINE to switch to another buyer (ibid.). The partnership with AFI has, however, also meant a technological upgrading of TINE in terms of an improved ability to produce bulk commodities from whey (ibid.). It remains to be seen whether the partnership can help TINE to further upgrade its whey-based business in terms of learning about more advanced products and processing techniques, or develop deeper market knowledge, and so strengthen its position in the value chain. In this regard, Vik and Kvam (2017) observe that AFI does not share knowledge about customers and prices with TINE to avoid losing control over TINE as a supplier. Finally, any upgrading strategy chosen by TINE needs to consider how to access new sources of whey raw material to achieve scale economies, given the geographical context and the domestic orientation of milk sourcing and sale of dairy products (see Table 9.3).

9.5.2 The sustainability of different valorisation pathways

Arla Foods has strategised on the valorisation of acid whey in a clever way. Instead of bringing large amounts of acid whey to a central processing facility, AFI sells a product to enable its customers to turn acid whey into a useful product. This is, however, not the same as saying this strategy is the most sustainable one for handling acid whey. For any product or product system to be deemed sustainable, it should at least have a better economic, social and environmental performance than other ways to achieve the same function. The term 'product system' does not only refer to the acid whey itself. For instance, when acid whey is used for human food production instead of feed production, one must also consider that other feed ingredients are needed to replace acid whey.

There are likely economic gains both for AFI and the dairy companies who buy Nutrilac® to valorise their acid whey. Livestock farmers, who lose a cheap feed ingredient, will have to replace this source with a probably costlier alternative, such as imported feed. This will of course create extra income for the farmers producing the feed alternative and for other actors in this value chain. This will again increase the demand for feed products with consequences for other value chains dependent on such products. Similarly, if acid whey is originally used for biogas, alternative substrates need to be found. Hence there are complex distributional and economic knock-on effects on the wider food (and energy) system of changing valorisation pathways for side streams such as acid whey, which can be important but at the same time difficult to measure.

A hypothesis in this regard is that when valorisation becomes more technically complex and costly, there is a risk that the distribution of wealth becomes more unequal. Repercussions in the environmental dimensions will follow similar paths to those in the social and economic dimensions, although the magnitude and the direction of impacts may be very different. As such, evaluating the valorisation of by-products cannot be performed in isolation. A usage which is conventionally seen as higher order, such as human food or medicines, may from a holistic perspective be less sustainable than solutions with lower levels of sophistication. While by-products should not be wasted, the development of sustainable valorisation pathways requires sophisticated assessment tools, such as life cycle assessment.

9.6 Conclusion

There are several potential valorisation pathways for acid whey, including as a component in animal feed, nutritional products, bakery products and beverages. Yet the dominant use today is as animal feed or as a biogas substrate in unprocessed form. Nutrilac® is a new whey protein, which enables the use of acid whey in a range of high-value products. In contrast, virtually all sweet whey is upcycled to value-added products, notably a variety of whey proteins and whey permeates used in the manufacturing of nutritional and functional foods. It has become a scarce resource.

Whey is the central side stream in the dairy sector and has been utilised differently in Denmark and Norway. Arla Foods, based in Denmark, has a stronger focus on utilising by-products, enabled by international market connections, R&D capabilities, a series of strategic domestic and international investments and the size of the regional dairy industry. A key factor has been the establishment of a subsidiary dedicated to whey processing, product development and marketing. Through these and other means, Arla Foods has gained a significant share of the market for whey-based ingredients, taking a leading position in the global value chain for these products. In Norway, the agriculture sector has mainly supplied the domestic market; in this context, TINE has focused on developing and manufacturing a variety of fresh dairy products for Norwegian consumers, rather than adding more value to its side streams. Hence, TINE lacks the advanced knowledge of whey products and processing techniques, the market connections and possibly the milk resource base, which are a necessary part of being a lead firm in the ingredients value chain. Instead it plays the role of 'captive' supplier of generic whey products to Arla Foods' ingredients subsidiary, AFI.

Even though AFI has found an efficient way of dealing with acid whey, the solution might also create a lock-in that hinders potential new solutions. Ideas that are generated in individual and possibly across industrial sectors may guide TINE in utilising their acid whey in innovative ways, although it lacks the systematic processes to search for these solutions.

Using whey as a raw material in production processes can not only improve a company's sustainable competitive advantage; it also aids the transition towards a sustainable bioeconomy. Innovation in waste systems results in lower disparate rates while increasing the ability to upcycle whey, adding value to by-products in the dairy value chain. When considering alternative valorisation options for by-products such as whey, it is important to take a holistic and whole-system perspective on sustainability. The most technologically advanced options are not necessarily the 'best' ones in terms of environmental, economic and social impacts and there will likely be trade-offs between these three dimensions of sustainability.

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